Estuarine, Coastal and Shelf Science 93 (2011) 14–26

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

# Carbonate sedimentation and hydrodynamic pattern on a modern temperate shelf: The strait of Bonifacio (western Mediterranean)

Giovanni De Falco [a,*], Sandro De Muro [b], Tiziana Batzella [b], Andrea Cucco [a]

[a] Istituto per l'Ambiente Marino Costiero del CNR, Località Sa Mardini 09170 Torregrande Oristano, Italy
[b] Dipartimento di Scienze della Terra Università degli studi di Cagliari, Via Trentino 51, 09127 Cagliari, Italy

ARTICLE INFO

*Article history:*
Received 26 July 2010
Accepted 22 March 2011
Available online 6 April 2011

*Keywords:*
biogenic
carbonate
*Posidonia oceanica*
Maërl
sediment
hydrodynamics

ABSTRACT

The sedimentary features of the inner-middle shelf of the strait of Bonifacio (western Mediterranean) were analyzed to evaluate the relationship between the production and transport of biogenic carbonate sediments and the basin morphology and hydrodynamics. A three-dimensional hydrodynamic modeling was performed in order to simulate the influence of waves and currents at seabed level. Superficial sediments were collected at depths ranging from 5 to 80 m and were analyzed for grain size, mineralogical composition and skeletal carbonate composition. *Posidonia oceanica* seagrass meadows border the coasts in a narrow strip on both sides of the strait down to a depth of 40 m. At greater depths, the seabed is characterized by the presence of plateaus and ridges which are controlled by outcropping bedrock morphology.

Waves and seabed currents are driven by the prevailing northwest and northeast winds. For both wind directions, higher values for the seabed current velocity, associated with wind-storm events, were detected in shallower sectors and along an east–west-oriented belt that connects the western Mediterranean and the Tyrrhenian Seas.

The sediments range from sand to gravel and show a mixed biogenic carbonate/siliciclastic composition. This is due to the carbonate production associated with benthic ecosystems and the mixing of modern carbonate with relict sediments.

Biogenic gravelly sands were found in association with *Posidonia oceanica* seagrass meadows and extended down to the circalittoral zone outside the deeper boundary of the meadows. This sedimentary facies was derived from the modern carbonate production associated with the *P. oceanica* ecosystem. Sediments collected outside the deeper limit of the meadows were identified as sediments deposited during the stand of the meadows at a deeper level during lower sea level conditions.

*Maërl* (free-living calcareous red algae) beds are the main carbonate factory and are mainly located at the top of the rocky plateaus (at ~50–55 m) formed by the outcropping of the bedrock. Downward, the increased currents at the seabed level in the east–west-oriented belt, which connects the western Mediterranean and the Tyrrhenian Seas, limit the extension of this carbonate factory. This results in a mixed sedimentary facies composed of biogenic carbonate and relict siliciclastic sandy gravel.

Compared to other Mediterranean shelves, the strait of Bonifacio is characterized by a distinct oceanographic setting. This is due to the connection between two basins. The currents at the seabed play a crucial role in controlling the distribution of the carbonate factories.



## 1. Introduction

The role of carbonate-producing organisms on cool-water continental shelves has been recognized increasingly in recent decades (e.g. Nelson, 1988; Carey et al., 1995; James, 1997; Pedley and Carannante, 2006). The study of modern temperate carbonate environments has also provided insight into the environmental interpretation of ancient deposits (Simone and Carannante, 1988; Martin et al., 1996; Betzler et al., 1997; Pomoni-Papaioannou et al., 2002; Pomar et al., 2004).

Carbonate sediments are generally present where the input of terrigenous sediments is low; otherwise, mixed carbonate-siliciclastic facies may occur due to the mixing of intrabasinal biogenic carbonate production with external terrigenous input,

* Corresponding author.
*E-mail address:* giovanni.defalco@cnr.it (G. De Falco).

0272-7714/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecss.2011.03.013

especially in the nearshore (Brandano and Civitelli, 2007; De Falco et al., 2008). Intrabasinal conditions (e.g., temperature, salinity and hydrodynamics) mainly control the biological production of carbonate (Pomar, 2001).

Modern carbonate depositional environments in the Mediterranean Sea have been described, especially from the western basin, where carbonate sedimentation has been reported to occur in low-energy isolated ramps (Balearic ramp, Fornós and Ahr, 1997; Pontine islands, Brandano and Civitelli, 2007), in attached shelves (Apulia-Adriatic sea, Toscano and Sorgente, 2002; Tropeano and Spalluto, 2006; Bay of Naples and Pozzuoli-Tyrrhenian Sea, Toscano et al., 2006) and isolated banks (Adventure Bank, strait of Sicily, Colantoni et al., 1985).

The production of biogenic carbonate debris is related to different benthic ecosystems of the infralittoral and the circalittoral zones associated with both unconsolidated and hard substrates (Pérès and Picard, 1964; Carannante et al. 1988; Canals and Ballesteros, 1997; Ballesteros, 2006). The definition of the depth limits of those zones is based on the occurrence of benthic ecosystems. The infralittoral zone is located between the lowest astronomical tide and the deepest occurrence of seagrass, whereas the circalittoral zone is located between the deeper limit of seagrass down to the maximum depth where sciophilous algae occur (Pérès and Picard, 1964). *Posidonia oceanica* seagrass meadows are recognized as a major ecosystem producing biogenic carbonate sediments in the infralittoral zone of the Mediterranean Sea, from the shoreline down to 40 m depth (Canals and Ballesteros, 1997; De Falco et al., 2008). Sediments collected inside the *P. oceanica* meadows in different Mediterranean sites show high percentages of biogenic carbonate due to the fauna, such as gastropods, foraminifers, bivalves, echinoids and bryozoans, associated with the ecosystems (Fornós and Ahr, 1997). Biogenic carbonate sediments produced in *P. oceanica* meadows can be reworked outside toward the nearshore and can affect the composition of adjacent beach sediments (De Falco et al., 2003).

In the circalittoral zone, the carbonate factory of mobile substrate is mainly related to the production from red algae, which typically form two types of sediments: the *Maërl* facies with free-living red algal branches and the '*facies à pralines*' dominated by rhodoliths (Carannante et al., 1988). Those facies are generally associated with bioclastic sediments deriving from carbonate fragment reworking in the mobile substrate, termed the '*détritique côtier*' by Pérès and Picard (1964).

Hydrodynamics is considered a major intrabasinal factor affecting biogenic carbonate sediment production (Pomar, 2001). Open ocean sites and land-locked water bodies exhibit marked differences in the depth distribution of carbonate sedimentary facies due to their differing wave energy regimes. Colonization and sediment preservation are enhanced in low energy ramps of semi-enclosed basins, such as the Mediterranean Sea (Fornós and Ahr, 1997; Pedley and Carannante, 2006). In contrast, bioclastic reworking occurs in the inner ramps of high-energy sites in open oceans, where the biozones occupy much deeper waters (Pedley and Carannante, 2006; Ryan et al., 2008).

Although the importance of hydrodynamics as a factor that controls the carbonate sedimentation is generally acknowledged, few studies have related waves and seabed currents with the distribution of carbonate sedimentary facies from the Mediterranean Sea. Wave height was found to be inversely related to the carbonate sediment production from *Posidonia oceanica* meadows from western Sardinia (De Falco et al., 2008). Hydrodynamics were also considered the main factor affecting the stability of algal nodules in the circalittoral zone of the Pontian islands (Basso, 1998), although quantitative data for the seabed current were not reported.

This paper evaluates the factors that control the sediment composition and facies distribution from the infralittoral to the circalittoral zones of the inner-middle shelf of the strait of Bonifacio (Western Mediterranean), a site characterized by a complex seabed morphology and oceanographic setting. The aim was to evaluate the role of hydrodynamics (including both waves and seabed currents) in the production and distribution of biogenic carbonate sediments.

## 2. Study area

The strait of Bonifacio, located between the islands of Sardinia and Corsica, separates two distinct basins (the western Mediterranean and Tyrrhenian Seas). The strait is an area of great interest from an environmental point of view and is included in the International Marine Park of *Bocche di Bonifacio* (Fig. 1).

In the region of the Bonifacio Strait the winds are orographically controlled. Analysis of the wind data has shown 52–54% of the winds are from the west and 26% from the east. The river inflows in the Strait are very weak and characterized by a seasonal torrent like regime. The rainfall is typical of the southern Mediterranean regions with an average of about 572 mm/year. Water circulation in the strait is strongly controlled by the wind; the maximum tidal range is about 0.25 m.

The water temperature varies from 15 °C in early spring, to between 19 and 25 °C in summer and autumn. The salinity is quite constant during the year due to the absence of significant inputs of fresh water. It ranges between 37.7 in spring and 38.8 in summer and autumn (Artale et al., 1994).

The Corsican-Sardinian block rotated counter-clockwise during the lower Miocene following the opening of the Ligurian basin. The geology of North Sardinia and South Corsica is dominated by the Hercynian batholiths from the upper Carboniferous-Permian age, which are outcroppings between the two islands ~400 km long and ~50 km wide characterized by different calco-alkaline granitic formations and fields of basic dikes. In Sardinia the post-Hercynian formations are limited to Quaternary deposits in the coastal areas and alluvial plains, with the exception of a very limited outcrop of Miocene limestone at the northern cape (Carmignani et al., 2001). Marine sedimentary rocks from the lower Miocene age outcrop in southern Corsica for a total surface area of ~25 $km^2$ (Carmignani and Rossi, 2000).

In the study sector, the depth did not exceed 80 m. The seabed morphology in the northern sector of the strait is characterized by the presence of the Bonifacio plateau at a depth of ~50–55 m, which is cut by channels converging toward the center of the basin (Fig. 1). Several ridges delimiting small basins characterize the eastern sector, sometimes emerging and forming minor islands (Lavezzi and La Maddalena archipelagos, Fig. 1). *Posidonia oceanica* meadows border the coasts of the main islands down to a depth of ~40 m and are quite extensive in the shallower sectors in proximity of the minor islands (Fig. 1).

The strait of Bonifacio was previously investigated using side-scan sonar data integrated with sediment sampling (Pluquet, 2006). Based on these data, Pluquet (2006) highlighted that two sedimentary facies (*sensu* Pérès and Picard, 1964) dominated the circalittoral zones: the 'coarse sands and fine gravels under the influence of bottom currents' and the '*détritique côtier*' (Pluquet, 2006). The first facies was mainly located at the top of the Bonifacio plateau and down to the deeper limit of *Posidonia oceanica* meadows, with the latter in the remaining sectors. The same author highlighted the presence of longitudinal bedforms, suggesting a strong influence of seabed currents on sediment transport in this area (Pluquet, 2006).